Overview

Executive Summary

Nutrition has been critical in every phase of exploration on Earth, from the time when scurvy plagued seafarers to the last century when polar explorers died from malnutrition or, in some cases, nutrient toxicities.

The space food system must provide food that is safe, nutritious, and acceptable to the crew, to maintain crew health and performance during space flight. Nutritional standards in NASA-STD-3001 are based on NIH standards with modifications for spaceflight environment. Achieving and maintaining food system acceptability, nutrition, and safety for spaceflight is complex and influenced by factors such as duration isolated from Earth, menu development, suitability in microgravity, packaging, and stowage.

Risks of Inadequate Food & Nutrition

- Performance decrement
  - Loss of endurance
  - Cognition changes
- Crew health
  - Bone loss[1]
  - Changes in immune function
  - Cardiovascular performance
  - Gastrointestinal function
  - Severe dehydration
  - Nausea
  - Diarrhea
  - Endocrine function
  - Ocular
  - Behavioral health[2]
  - Renal stones
  - Ability to mitigate oxidative damage
- Nutritional deficiencies or toxicities
  - Weight loss
  - Sleep loss
  - Dehydration
- Long-term health effects
  - Cancer
  - Musculoskeletal changes
- Drug/nutrient interactions

Summary of Standards

V2 6029 Drinking Water Quantity
V2 6030 Food Rehydration Water Quantity
V2 6031 Hot Rehydration Water Quantity
V2 6035 Water Quantity for Suited EVA Operations
V2 6039 Water Dispensing Rate
V2 6040 Water Dispensing Increments
V2 6041 Hot Beverage Water Temperature
V2 6042 Cold Beverage Water Temperature
V2 6043 Food Hydration Water Temperature
V2 7001 Food Quality
V2 7002 Food Acceptability
V2 7003 Food Caloric Content
V2 7004 EVA Food Caloric Content
V2 7005 Food Macronutrients
V2 7006 Food Micronutrients
V2 7007 Food Microorganism Levels
V2 7008 Food Preparation
V2 7009 Food Preparation and Cleanup
V2 7010 Food Contamination Control
V2 7011 Food and Beverage Heating
V2 7012 Dining Accommodations
V2 7013 Food System Waste
V2 7014 Food Spill Control
V2 7015 Food System Cleaning and Sanitizing

1. Bone Loss and Prevention Technical Brief
2. Behavioral Health and Performance Technical Brief

This Technical Brief is derived from NASA-STD-3001 and is for reference only.
It does not supersede or waive existing Agency, Program, or Contract requirements.

Background

"An army marches on its stomach." – Napoleon Bonaparte

Throughout history, one of the performance affecting factors for all expeditions or explorations, was the availability of an adequate food supply. Even with today's advancements, the need for adequate and acceptable food is underestimated as evidenced by illness and weight loss experienced during human expeditions.

Historical Events

1897-1899 *Belgica* Expedition (Cook)
- Beri beri (thiamine deficiency) that led to death, shortness of breath, irregular heart rate and edema

1910-1913 *Terra Nova* Expedition (Scott)
- Weight loss due to inadequate caloric intake that was 1500-3000 kcal less than expended
- Inadequate wound healing due to Vitamin C deficiency that led to skin rotting, loss of nails and a hand wound that began to suppurate

Gemini, Apollo, Skylab, ASTP, and ISS flights
- Weight loss occurred even during the short durations due, in part, to food acceptability

Biosphere 2
- Weight loss of 14-21% due to inadequate food availability

Mars 500
- "Food became probably the greatest problem in isolation"

Food System Evolution

Mercury – Semi-solid, sterile, tubed foods, fruits, and meat combinations packaged in collapsible aluminum tubes. Supplementing the semi-solid foods were special dry bite-size foods.

Gemini – More complex, all dehydrated food system with more meals per person per day. Some of the bite-size foods had to be altered to control crumb problems.

Apollo – Greater attention was focused on astronaut preferences which resulted in greater menu variation of both bite-sized and rehydratable foods. Hot water was available for food rehydration and "wet packs" were introduced.

Skylab – Efforts were focused on making the food a positive morale factor by including variety and acceptance. Menus were on a 6-day cycle and proving more consistent nutrient content. Freezer foods were provided and warmer for canned foods.

Apollo-Soyuz Test Project (ASTP) – Introduction of freeze-dried foods and redappertized meats. No freezer or food warmer available, along with limited water.

Shuttle – Redesigned packaging of rehydratables and improved galley that included convection oven and rehydration unit.

Source: Food for U.S. Manned Spaceflight

Reference Information

Food Acceptability Considerations

Past experience and personal preference – The ability to choose and consume foods that are familiar and the availability of personal favorites can become more important in isolation and confinement, and considerations are needed for international crews.

Variety – Food can lose its acceptance if eaten too frequently. A wide variety of foods to choose from is desirable.

-The US military limits the use of MREs to 21 consecutive days to prevent health and performance impacts due to inadequate food consumption.

Availability – Snacks should be available with a minimum of preparation, which is particularly important for high-energy-output tasks such as extravehicular activity (EVA) operations.

Food form – Food quality that is more familiar and "Earth-normal" will facilitate acceptability of the food and subsequent consumption.

Meal scheduling – Lack of consistent meal periods in the crew schedule can lead to skipped meals and undernourishment.

-Crew days are planned to ensure there is adequate time for meals, as well as time for dining together as a team.

-Consider the needs for days with EVAs and specific needs of those activities

NASA astronaut Kjell Lindgren (left) and Japan Aerospace Exploration Agency (JAXA) astronaut Kimiya Yui, participate in a food tasting session.

Meal Preparation Time – Complexity of preparation, including rehydration and heating, can lead to skipped meals or incomplete consumption due to time constraints from crew day scheduling.

Microgravity environment – Anecdotally, some crewmembers have reported that changes occur in their taste and odor perception of foods during spaceflights, which may be influenced by factors such as bodily fluid shift, changes in air circulation, and competing odors in the closed spacecraft. Condiments are flown to allow the crewmembers to individually alter the flavors of the foods.

-Some crew have noted that spicier foods are desired due to the lack of smell or taste.

Waste management facilities – Inadequate body waste management facilities have discouraged food consumption.

-Previous crew comments have noted that the smell from the waste management system has caused appetites to be affected from smells.

Space adaptation sickness (SAS) – Control of SAS is essential for a healthy appetite.

-Crew have medications available to them to help mitigate this occurrence, as well as having the flexibility on consuming less solids while maintaining hydration with the available water quantities.

Atmospheric contaminants – Buildup of background odors during missions could contribute subliminally to a decrease in appetite and consumption.

-This could include the stowage of trash, as well as the off-gassing from various chemicals used or payloads.

STS-113 crewmembers are briefed by dietitians during a food tasting.

Reference Information

Food Nutrition

Current macronutrient and micronutrient guidelines for spaceflight reflect the latest Dietary Reference Intakes (2011) as suggested by the National Institutes of Health, except the following due to the increased needs of the body from the impacts of spaceflight:

- **Vitamin D** – Increased quantities to counter to the limited UV exposure from sunlight and limited dietary sources
- **Vitamin B6** – Increased quantities to counter the deficiency of B6 from the associated muscle loss from long duration spaceflight

Estimated Energy Requirements

EER for men 19 years old and older

$$\text{EER (kcal/day)} = 622 - 9.53 \times \text{Age [y]} + 1.25 \times (15.9 \times \text{Mass [kg]} + 539.6 \times \text{Height [m]})$$

EER for women 19 years old and older

$$\text{EER} = 354 - 6.91 \times \text{Age [y]} + 1.25 \times (9.36 \times \text{Mass [kg]} + 726 \times \text{Height [m]})$$

Note: For EVA operations, up to an additional 500 kilocalories per EVA hour must be provided for EVA crewmembers. Additional energy and nutrients are necessary during EVA operations, as crewmember energy expenditure is greater during those activities.

Food and Water Intake for Spaceflight Programs

Nutrient Intake Data

Updated nutrient intake data for several space programs are reported below. For ISS, we report the data on nutrients available from the Food Frequency Questionnaire analysis. Data on planned ISS menu content and information on a wider range of nutrients are available online at http://go.nasa.gov/QS1KW1 (2).

	Apollo	Skylab	Shuttle	ISS (E1-13)	ISS (E14-25)	ISS (E26-37)
N	33	9	32	19	19	17
Energy, kcal/d	1880 ± 415[a]	2897 ± 447	2090 ± 440	2313 ± 514	2317 ± 591	2444 ± 536
Energy, % WHO	64.2 ± 13.6	99.1 ± 8.2	74.2 ± 16.0	79 ± 18	83 ± 17	84 ± 15
Protein intake, g/d	76.1 ± 18.7	111.0 ± 18.4	78.0 ± 18.8	102 ± 25	96 ± 34	109 ± 30
Protein intake, % of kcal	16.3 ± 2.1	15.7 ± 2.1	14.9 ± 2.4	18 ± 2	16 ± 2	18 ± 2
Carbohydrate intake, g/d	268.9 ± 49.1	413.3 ± 59.3	304.0 ± 67.3			
Carbohydrate intake, % of kcal	58.1 ± 7.1	57.5 ± 9.1	58.4 ± 5.0			
Fat intake, g/d	61.4 ± 21.4	83.2 ± 13.8	64.0 ± 17.8			
Fat intake, % of kcal	28.9 ± 5.5	26.8 ± 8.6	27.2 ± 4.4			
Calcium, mg/d	774 ± 212	894 ± 142	826 ± 207	878 ± 274	944 ± 258	1074 ± 205
Phosphorus, mg/d	1122 ± 325	1760 ± 267	1216 ± 289			
Magnesium, mg/d		310 ± 58	294 ± 74			
Iron, mg/d			15.0 ± 3.9	18 ± 5	18 ± 5	20 ± 5
Zinc, mg/d			12.0 ± 2.9			
Sodium, mg/d	3666 ± 890	5185 ± 948	3984 ± 853	4601 ± 1239	4658 ± 1593	3823 ± 785
Potassium, mg/d	2039 ± 673	3854 ± 567	2391 ± 565	3315 ± 513	3214 ± 863	3559 ± 784
Water, g/d	1647 ± 188[b]	2829 ± 529	2223 ± 669	2012 ± 462	2142 ± 387	2320 ± 581

Abbreviations: E, expedition numbers of ISS missions; ISS, International Space Station; WHO, World Health Organization.

[a]All data are mean ± SD. Empty cells show where data were not available. Data updated and expanded from earlier reports (2, 826).

[b]n=3 for water intake during Apollo missions.

Source: Human Adaptation to Spaceflight: The Role of Nutrition, Smith, Scott M. et al.

Current ISS Standard Food System

<u>8 Standard Categories – feeds a crew of three for 7-9 days</u>

1. Breakfast
2. Rehydratable Meats
3. Meat and Fish
4. Side Dishes
5. Vegetables and Soups
6. Fruits and Nuts
7. Desserts and Snacks
8. Beverages

<u>Supplemental Categories</u>

9. Personal Preference
10. Condiments
11. Fresh foods (periodic)

<u>Current Average Consumption</u>

Calories 2365
Fat 29% / Sat Fat 10%
Carbs 51%
Protein 20%
Sodium 2573mg

<u>Food Prep Equipment</u>

Hot metered water
Ambient water
Food warmer
Small chiller

"The soldier who is well fed is not only in better bodily health and better able to resist disease, but he is more cheerful in difficulties and therefore more equal to any strain he may be called upon to endure." – Surgeon-Lieutenant-Colonel GS Robinson

Reference Information

Food Safety During Production

Food safety is defined by the absence of a health risk due to physical, chemical and microbiological contamination.

Contamination Sources

- **Waste and Hygiene Areas**[1] – microbes that can lead to gastrointestinal illnesses
- **Air** – odors that are not properly contained
- **Water Sources** – microbial contamination, leeching or biocides
- **Packaging** – must be food grade
- **Eating Utensils** – forks, straws, etc
- **Chemical Sources** – cleaning materials used in the same area that leave a residue or have off-gassing
- **Physical Debris** – dirt, regolith, wood, plastic and other small objects
- **Fresh fruits and vegetables** – direct shipment from the ground, items that are picked and then eaten

Considerations

Staging of food should consider long duration storage and temperatures to ensure food quality and acceptability.

Prepositioning of foods

- Lack of available fresh fruits/vegetables
- Lack of preferences
- Stability of food micro- and macronutrients
- Preservation of food quality

1. Body Waste Management Technical Brief

Area/Item	Microorganism Tolerances	
Food Production Area	**Samples Collected**	**Limits**
Surfaces	3 surfaces sampled per day[a]	3 colony-forming units (CFU)/cm^2 (Total aerobic count)
Packaging Materials	Before use	
Air	1 sample of 320 liters monthly	113 CFU/320 liters (Total aerobic count)
Food Product	**Factor**	**Limits**
Non-thermostabilized[b]	Total aerobic count	20,000 CFU/g for any single sample (or if any two samples from a lot exceed 10,000 CFU/g)
	Enterobacteriaceae	100 CFU/g for any single sample (or if any two samples from a lot exceed 10 CFU/g). No detected serious or severe hazard human enteric pathogenic organism
	Salmonella	0 CFU/g for any single sample
	Yeasts and molds	1000 CFU/g for any single sample (or if any two samples from a lot exceed 100 CFU/g or if any two samples from a lot exceed 10 CFU/g *Asperfillis flavus*)
Commercially Sterile Products (thermostabilized and irradiated)	No sample submitted for microbiological analysis	100% inspection for package integrity

a. Samples collected before food processing on days that the food facility is in operation. Environmental samples will be collected when there is a 1-hour break in activity, or after five hours of continuous work.
b. Food samples that are considered “finished” products that require no additional repackaging are only tested for total aerobic counts.

Application Notes

Food/Packaging Type	ISS Example	Parameters
Thermostabilized – heating food to a temperature that renders it free of pathogens, spoilage microorganisms, and enzyme activity	Beef stew, Chocolate Pudding, Split Pea Soup, Tuna casserole, Red beans & rice	**Shelf life:** 2 years **Packaging:** Quad-laminate pouch **Preparation:** None or heating **Mass:** 3.07 to 8.32 oz (87 to 236 g)
Irradiated – use of gamma rays, X rays, or electrons, and uses energy levels that ensure negative induction of radioactivity in the irradiated product. Irradiation controls naturally occurring processes such as ripening or senescence of raw fruits and vegetables, and is effective to inactivate spoilage and pathogenic microorganisms	Beef fajitas, Smoked turkey	**Shelf life:** 2 years **Packaging:** Quad-laminate pouch **Preparation:** None or heating **Mass:** 3.03 to 6.94 oz (86 to 197 g)
Rehydratable – are drying with heat, osmotic drying, and freeze drying	Vegetables, Chicken salad, Cornbread dressing, Sausage patty, Shrimp cocktail	**Shelf life:** 1.5 years with overwrap; 1 year with no overwrap **Packaging:** Combitherm pouch, adapter for rehydration **Preparation:** Rehydration using hot or cold Water **Mass:** 0.88 to 3.40 oz (25.0 to 96.6 g)
Natural form – these foods rely on reduced water activity to prevent microbial activity	Cookies, Brownies, Nuts, Granola bars	**Shelf life:** 1.5 years with overwrap; 1 year with no overwrap **Packaging:** Combitherm pouch **Preparation:** None **Mass:** 0.74 to 2.43 oz (21 to 69 g)
Extended-shelf-life bread products – the products must be specially formulated to a water activity level low enough to prevent the growth of anaerobic pathogenic bacteria	Tortillas, Wheat flat bread	**Shelf life:** 1 year **Packaging:** Quad laminate or packaged by Department of Defense **Preparation:** None
Fresh food – foods with a short shelf life and no processing	Fresh fruit, Raw vegetables, Fresh tortillas	**Shelf life:** 1 week **Packaging:** None **Preparation:** None
Beverages – either freeze-dried beverage mixes (e.g., coffee or tea) or flavored drinks (e.g., lemonade, orange drink, etc.)	Freeze-dried (coffee or tea), Drink mix (lemonade), Water	**Shelf life:** 3 years **Packaging:** Tri-laminate pouch, adapter for rehydration, straw **Preparation:** Rehydration using hot or cold water **Mass:** 0.42 to 1.90 oz (12.0 to 54.0 g)

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Application Notes
Space Food System Design

Food Development – Foods must be developed to be safe, nutritious, and acceptable, and to meet mission requirements.

Mission Requirements –Missions up to three days in length may have mass and power constraints that do not support certain types of foods, such as rehydratables and heated foods. As mission length increases (> that 30 days) menu cycle length must increase (over an eight day menu) to provide variety, which promotes consumption.

Technical Challenges
- Nutrient-dense, shelf stable foods that meet overall sensory acceptability metrics
- Menu items with at least a 5-year shelf life
- Partial gravity cooking processes that minimize microbial risk
- Stable sustained vitamin delivery
- High-barrier, low-mass, & process compatible packaging materials

Development of Food Products – food products are developed with consideration for nutritional content, safety, and acceptability, as well as:
- **storage duration** (based on mission duration plus the time required to process, test, and ship the foods for launch) and **shelf life** (based on each food's composition and preparation method)
- **packaging type** is essential for maintaining safety, nutritional quality, and acceptability throughout shelf life – food packaging must meet safety and gaseous pollutant specifications
- **suitability for use in microgravity**, for example, foods that produce crumbs (such as crackers) should be provided in bite-sized pieces to minimize debris; meal items should contain enough moisture to stay in the package or on a utensil through surface tension

Menu Development (personal preference vs standard menu) –personal preference coupled with providing a standard menu for use by all crew is considered. The overall menu needs to ensure that the total nutrient requirements are met while providing acceptability and variety for the crew

Food Stowage – Food may be stowed in various configurations, as long as the packages are protected from puncture or damage during transport and in mission.

Expertise – NASA utilizes the following expertise to develop and provide a food system:
- **food scientists** develop food specifications, confirm safety, confirm shelf life, and suitability
- **registered dietitians** develop menus and confirm nutritional content.
- **packaging engineers** develop and test package integrity (sealing and vacuum) of packaged foods
- **logistics specialists** develop stowage procedures and monitor food inventory
- **food system engineer** design food processing equipment to rehydrate and heat food

Facilities – Proper facilities such as an analytical lab, food processing plant, packaging room, sensory facility and stowage room are needed to maintain the food quality and safety.

References

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Other Standards for Consideration

V2 3006 Human-Centered Task Analysis[1]
V2 6026 Water Physiochemical Limits
V2 6027 Water Microbial Limits
V2 6105 Total Iodine Concentration at the Point of Consumption
V2 7052 Stowage Location
V2 8001 Volume Allocation
V2 11025 Suited Nutrition
V2 11029 LEA Suited Hydration
V2 11030 EVA Suited Hydration
V2 11037 Suited Metabolic Rate Measurement
V2 11038 Suited Metabolic Rate Display

Skylab Food System

1. Human-Centered Task & Error Analysis Technical Brief